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Effect of freezing rate in textural and rheological characteristics of frozen cooked organic pasta

Daniela F. Olivera, Viviana O. Salvadori *

CIDCA (Centro de Investigación y Desarrollo en Criotecnología de Alimentos), Facultad de Ciencias Exactas (UNLP) y CONICET, MODIAL, Departamento de Ingeniería Química, Facultad de Ingeniería (UNLP), 47 y 116 (B1900AAJ) La Plata, Argentina

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ABSTRACT

The ready-meals market has grown significantly in developed countries over the past decade. In particular, organic pasta entirely formulated with organic ingredients and marketed as ready-to-eat meals, is an excellent choice of processed organic food.

Of the available preservation technologies, freezing has been recognized as an excellent method of preserving the quality characteristics of foods. The aim of this work was to study the influence of two freezing conditions (air blast and cryogenic) on the quality of cooked organic pasta, in particular organic tagliatelle. Textural characteristics (textural profile analysis) and rheological measurements (relaxation and dynamic oscillatory tests) were performed in fresh cooked and frozen cooked pasta. The experimental results confirm that freezing produces structural damage in both frozen cooked organic pasta, the elasticity, the firmness and the water holding capacity being the more affected parameters. Textural analysis demonstrated that freezing rate was directly correlated to their derived parameters. A sensory analysis confirmed that instrumental results are detected by consumers.

1. Introduction

The ready-meals market has grown significantly in developed countries over the past decade (Redmond et al., 2005). Consumers demand fresh, healthy, safe and good quality foods.

However, some studies show that the replacement of home-made meals by ready-meals is dependent on how consumers relate sensory and health-related benefits with convenience features (Costa et al., 2007). In particular, recent studies suggest that potential organic food consumers are willing to pay premium prices for such products, even for those with less than 100% organic ingredients (Batte et al., 2007). In this context, organic pasta entirely formulated with organic ingredients and marketed as ready-to-eat meals, is an excellent choice of processed organic food, with a considerable value added (Olivera, 2005).

Concerning the preservation technologies applied to these products, freezing has been recognized as an excellent method of preserving the quality characteristics of foods: taste, texture and nutritional value (Raid, 1998). Although consumers perceive chilled ready-meals to be less-processed and more convenient (Knott, 2006), the advantage of frozen meals is their extended shelf-life (Kindt et al., 2006).

Freezing produces important changes in food structure, the transformation of liquid water into ice being the most relevant. Hence, it is essential to analyze in which way these changes affect the final quality of the frozen product. Several works have demonstrated that the rate of freezing is directly related to the size of ice crystals, and, consequently, to the structural damage (Spiess, 1980; Heldman and Taylor, 1998). Although the study of the dependence of ice structure in food on freezing rate has been mostly qualitative, some specific studies have quantitatively related ice crystals size with freezing rate in beef (Bevilacqua et al., 1979), apple tissues (Bomben and King, 1982) and food models (Woinet et al., 1998). Chevalier et al. (2000) analyzed the influence of different freezing methods (air blast and brine freezing) on the rate of ice crystals formation in a gel contained in a cylindrical mold. They concluded that the mean ice crystal diameter varies inversely to a local freezing rate.

The aim of this work was to study the influence of two freezing conditions (air blast and cryogenic) on the quality of cooked organic tagliatelle, measured by its textural and sensory properties. Few studies on this subject can be found in the literature. Irie et al. (2004) examined moisture distribution by magnetic resonance imaging (MRI) in cooked spaghetti of different origin (fresh, dried, frozen, luncheon and long-life spaghetti). Their results confirm that moisture distribution is the primary factor in determining the texture of cooked spaghetti. Only one work (Redmond et al., 2005) investigates the effect of short and long term chilled and frozen

* Corresponding author. Tel./fax: +54 221 4890741/4254853/4249287.
E-mail address: vosalvad@ing.unlp.edu.ar (V.O. Salvadori).

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storage of lasagna, a prepared meal with several components: various layers of pasta filled with vegetables or meat and covered with sauce.

To accomplish this objective, the textural and rheological characteristics of frozen cooked pasta were studied, by means of different instrumental analysis: TPA, relaxation test and dynamic oscillatory test. The parameters of both frozen samples were compared to that of fresh cooked pasta.

Also, to analyze whether the instrumental results on thawed samples still applied after reheating, the sensory properties of pasta were evaluated by means of acceptability study carried out with an untrained panel.

2. Materials and methods

2.1. Sample preparation

Hundred grams of organic dough were prepared according to the following recipe: 62.5 g of whole-wheat flour and 37.5 g of entire egg (white and yolk), both ingredients were organic certified.

The ingredients were mixed for 5 min in a home multi-function food processor Rowenta Universo (700 W), at a constant speed of 100 s^{-1}. Sheets of uniform thickness were obtained with a manual dough sheeter and samples (tagliatelle) of 0.01 m × 0.08 m × 0.001 m were cut.

Pasta samples were cooked in abundant boiling water and optimum cooking times were determined according to AACC 66-50 method (AACC, 2000). After being cooked, the product was drained, immersed in a mixture of ice-distilled water for 1 min to stop cooking, drained again and its surface was dried with paper towels.

Prior to freezing, individual aluminum trays of 0.14 m × 0.10 m × 0.045 m were filled with 0.2 kg of cooked tagliatelle (approx 4 cm height), and covered with a sheet of aluminum paper.

2.2. Freezing

With the aim of evaluating the influence of the rate of freezing, the samples were frozen in two freezers: (i) a cryogenic cabinet, PRAXAIR, which works with liquid N2 creating a cold atmosphere at −40 °C ± 1 °C, (ii) a prototype air-blast tunnel, which works with air at −35 °C ± 3 °C and air velocity of 0.3 m/s. In each experimental procedure, ten trays filled with cooked pasta, initially at ambient temperature, were placed inside the freezer. Three trials were performed for each freezing condition.

Sample temperature was measured by T-thermocouples connected to a data acquisition module, Keithley DASTC, plugged into a PC, using a recording interval of 1 s. Four trays were recorded in each trial. Freezing was completed when the temperature measured in the thermal center of each sample reached −18 °C. Air temperatures over the product surface were recorded with DS1921G Thermochron iButton temperature sensors, using a recording interval of 1 s.

Freezing rates FR (in °C/s) were determined according to Eq. (1), based on the definition given by the International Institute of Refrigeration (1986):

$$\mathrm{FR} = \frac{T_2 - T_1}{t_2 - t_1} \tag{1}$$

where T_1 is the initial freezing temperature, T_2 is the final freezing point (−18 °C), and (t_2−t_1) is the time elapsed between the beginning and the end of freezing.

In order to perform the texture and rheological measurements, the samples were thawed under controlled conditions in a cold store at 4 °C (±0.5 °C). Thawing time in this condition was 4 h.

2.3. Moisture content

Moisture of samples (prior and post freezing) was determined following AOAC official method 925.09 (AOAC, 1995): approximately 5 g of cooked pasta, placed in a previously weighed container were dried in a vacuum stove at 70 °C until they reached a constant weight. The moisture content (in percentage) of the sample is calculated according to Eq. (2):

$$M(\%) = \frac{W_\mathrm{i} - W_\mathrm{f}}{W_\mathrm{i}} \times 100 \tag{2}$$

where W_i is the initial sample weight, W_f is the final sample weight and $M(\%)$ is the percentage moisture content, in wet basis.

2.4. Texture analysis

The textural characteristics of cooked pasta play an essential role in determining the global acceptability of the food by consumers (Cole, 1991). A good quality pasta product should present certain degrees of firmness and elasticity, absence of stickiness, appearance uniformity and structural integrity (Edwards et al., 1993; Sozer et al., 2007).

A TA.XT2i Texture Analyzer (Stable Micro Systems, Surrey, UK) was used to perform the texture profile analysis. This analysis provides a significant measurement of the textural characteristics of the product (Szczesniak, 2002; Olivera and Salvadori, 2006).

The experimental procedure was as follows: one tagliatelle was placed on the base and was compressed twice to give a two complete compression-relaxation-tension profile curve. The settings of the experiments were the following: 25 mm flat-end aluminum compression disc (probe P/25), test speed 0.5 mm/s, distance 20% strain, data acquisition rate 50 pps, load cell 5 kg. Six replicates were made for each sample. The data was processed using Texture Expert Excede v. 1.0 (Stable Micro Systems Software).

2.5. Rheological measurements

Rheology is an important instrument to understand food response to stress and strain forces and offers valid information about food structure and the interaction between the different components. The rheological characterization is important for texture, stability and process design (Navarro et al., 1995).

Specific studies show that freezing and frozen storage affects considerably the rheological characteristics of fermented and non-fermented dough (Ribotta et al., 2004).

With the aim of studying the influence of freezing in cooked pasta structure, both mechanical and viscoelastic properties were determined. Two complementary assays were performed: relaxation and dynamic oscillatory tests.

The information provided by these combined tests, using small and large deformations, has proved to be useful in determining textural characteristics in different pasta: Edwards et al. (1993) studied the effect of cooking time in final texture, Ross (2006) reviewed the different studies about the changes in texture of Asian noodles after changes in amylose and protein composition.

2.5.1. Relaxation test

The described TA.XT2i Texture Analyzer was used for the relaxation assays. The sample (frozen and thawed tagliatelle) was placed in the equipment platform, a fixed compression strain was set and the variation of the tensile strength with time was registered.

The settings of this analysis were the following: test speed 0.5 mm/s, compression strain 20%, time 600 s. Six replicates for each sample were made.

The relaxation curves provide a way of measuring the viscoelastic properties of solids. In the systems analyzed in this study, the sample behavior can be characterized by the Maxwell model, combining one elastic ideal element (string) in parallel with various composed Maxwell elements (a string element with a viscous element in series) (Steffe, 1996). Mathematically the Maxwell model is represented by Eq. (3):

$$F(t) = F(t)/F_0 = A_\infty + \sum_{i=1}^{n} A_i \exp(-t/\tau_i) \quad (3)$$

where $F(t)$ is the instant force during the relaxation test, F_0 is the maximum value (before the beginning of tensile decay), A_i (dimensionless) are the coefficients related to the material viscoelastic properties and τ_i (s) are the relaxation times. The parameters were adjusted using nonlinear regression software (OriginPro 7.0).

From the regression coefficients (A_i and τ_i) the rheological parameters, elasticity modulus (E_i) and viscosity (η_i), were calculated:

$$E_i = \frac{A_i F_0}{a\varepsilon} \quad \eta_i = E_i \tau_i \quad (4)$$

2.5.2. Dynamic oscillatory test

Dynamic rheological tests were performed in a Rheometer RS600 (Haake, Germany), fitted with 35-mm parallel serrated plates (PP35/S), with a gap of 0.8 mm. Silicone was added around the plate edges to prevent sample dehydration. Temperature was maintained at 20 °C and oscillation frequency varied between 0.1 and 100 Hz. The viscoelastic linear region was identified by assays at different levels of applied stress at a fixed frequency (6.28 Hz). Each test was performed three times. A strain of 1% was used in this study to assure the tests were conducted in the linear range.

The experimental procedure allows the recording of storage modulus G' and loss modulus G'' vs. time and oscillation frequency.

The storage modulus G' indicates the elastic behavior of the food, while the loss modulus G'' measure the viscous characteristics of food. The loss tangent, $\tan\delta$, is a relative measurement of both contributions, viscous and elastic ones, and indicates which characteristic prevails.

2.6. Sensory analysis

In order to test the acceptability of the product, a sensory analysis was carried out, using a semi-structured hedonic scale (Cocci et al., 2008; Meilgaard et al., 2006).

A panel 30-member of untrained consumers, with some experience on sensory evaluation, was recruited.

The three pasta samples (control, quick frozen and slow frozen), were heated in an oven at 180 °C for 5 min, served and coded in random order in 60 ml capacity plastic cups and immediately presented individually to panelists. Panelists rinsed their mouths with bottled spring water between samples.

The tested attributes were the appearance (related to color), flavor, consistency (related to texture) and global acceptability. Each panelist received a form sheet to evaluate the mentioned attributes, using a nine-point hedonic scale anchored with "Like Extremely" and "Dislike Extremely" at either end, with a neutral point of neither "Neither Like nor Dislike".

The tests were performed in an isolated room with good illumination and natural ventilation, in groups of 10 subjects at a time.

For each descriptor (appearance, flavor, consistency and global acceptability.) an analysis of variance (ANOVA) was carried out to test significant differences ($P < 0.05$) attributable to samples.

2.7. Statistical analysis

Analysis of variance and pairwise comparisons were computed using the SYSTAT software (SYSTAT, Inc., Evanston, IL). Differences in means and F-tests were considered only when $P < 0.05$.

3. Results and discussion

3.1. Freezing of cooked pasta

Fig. 1 shows the temperature evolution of pasta frozen in the cryogenic equipment as well as in the blast tunnel. Experimental freezing times, defined as the time elapsed between initial temperature and the time at which center temperature reaches −18 °C, was 18 min (SD = 2.7) in the cryogenic freezing and 68 min (SD = 4.03) in the air blast freezing procedure, respectively.

Freezing rates of both conditions were calculated by Eq. (1), the initial freezing temperature T_1, evaluated from the slope of the freezing curve of Fig. 1 that was −1.2 °C (SD = 0.12).

The respective freezing rates were 0.98 °C min^{-1} for the cryogenic freezing and 0.32 °C min^{-1} for the air tunnel freezing. The first value is representative of fast freezing (above 0.83 °C/min). Instead, the tunnel's freezing rate is relatively slow in relation to commercial freezing rates, ranged between 0.20 and 0.83 °C/min (Brown, 1991).

According to most authors, the quality of a frozen food is directly related to the ice crystals size, which depends on the freezing rate. Fast freezing produces a large number of very small ice crystals, with a low damage to the cellular structure and consequently better final frozen products. Slow freezing, on the other hand, promoted large ice crystals (Löndahl et al., 1995).

Notwithstanding, other researchers had developed another classification of foods according to their sensitivity against freezing rate (Poulsen, 1977):

Group 1: Products which are not practically affected by the freezing rate.

Group 2: Products which require a minimum freezing rate (0.5–1 °C/min), higher freezing rates do not improve quality.

Group 3: Products whose quality improves when freezing rates are increased (3–6 °C/min).

Group 4: Products that are sensitive to too high freezing rates and tend to crack.

Ready-to-serve meals on a flour basis are included in Group 2 (Spiess, 1988). In this context, it is expected that the quality characteristics of frozen pasta will not be affected by cryogenic freezing. Instead, the air-blast freezing condition, in which the product is frozen with a freezing rate lower than 0.5 °C/min, will show evidence of its low freezing rate.

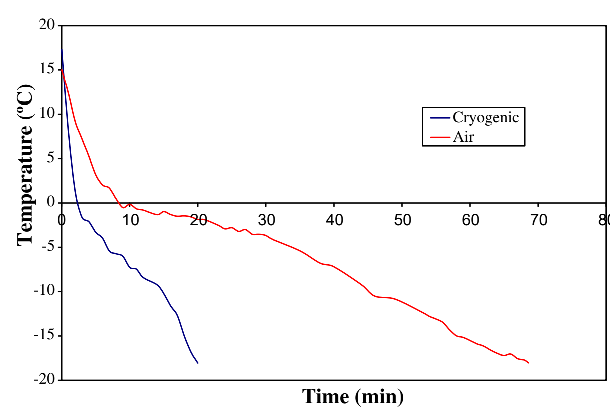

Fig. 1. Freezing curve of cooked pasta.

3.2. Moisture content

Table 1 shows the moisture content (wet basis) for both samples. These values confirm the influence of the freezing rate on the quality of the product: the moisture content of the pasta frozen in the cryogenic equipment does not differ from the initial value. Notwithstanding, the moisture content of the samples frozen in the slow freezing condition are significatively lower (2.5%) than their initial value, this weight loss is probably due to the structural damage of the pasta which promotes drip when the product is thawed (Löndahl et al., 1995; Redmond et al., 2005).

3.3. Texture profile analysis (TPA)

Fig. 2 shows a typical graphic registered from the texture profile analysis of cooked pasta and both frozen cooked samples.

From the areas and peak values different texture parameters were calculated: hardness, adhesiveness, consistency, cohesiveness and masticability (Szczesniak, 2002; Olivera and Salvadori, 2006).

Table 2 presents the average values and the standard deviation of the mentioned parameters.

When comparing the TPA parameters of the unfrozen cooked pasta and cryogenic frozen sample not significant differences were found, except for adhesiveness, being lower for the frozen sample.

Table 1
Moisture content (wet basis) of fresh cooked and frozen cooked pasta

	Fresh		Cryogenic		Air blast tunnel	
	Average	SD	Average	SD	Average	SD
Moisture (%)	63.34^a	1.2	62.91^a	1.08	61.35^b	1.06

Mean values in the same row followed by same letter do not differ ($\alpha = 0.05$).

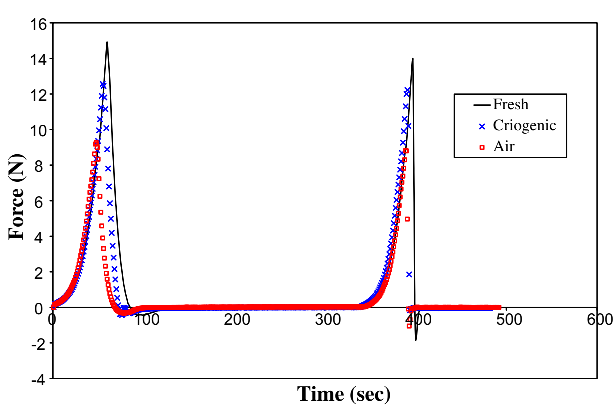

Fig. 2. Typical texture profile of fresh cooked and frozen cooked pasta.

Table 2
TPA results of fresh cooked and frozen cooked pasta

	Fresh		Cryogenic		Air blast tunnel	
	Average	SD	Average	SD	Average	SD
Hardness (N)	14.42^a	0.82	13.15^a	0.47	9.70^b	0.47
Adhesiveness (Ns)	−0.99^a	0.23	−0.41^b	0.11	−0.50^b	0.11
Cohesiveness	0.69^a	0.06	0.71^a	0.08	0.60^b	0.06
Consistency(Ns)	11.99^a	1.15	10.82^a	1.13	7.05^b	1.43
Springiness (s)	0.55^a	0.05	0.50^a	0.03	0.52^a	0.04
Masticability	4.77^a	0.23	4.94^a	0.20	3.02^b	0.20

Mean values in the same row followed by same letter do not differ ($\alpha = 0.05$).

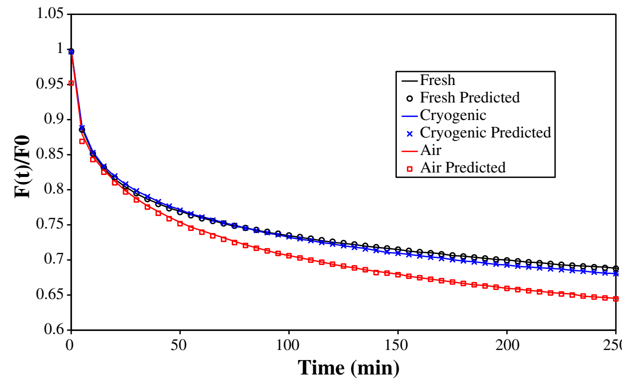

Fig. 3. Evolution of F/F_0 with time, obtained from the relaxation test, for both fresh cooked and frozen cooked pasta.

These results confirm that the texture is not influenced by fast freezing.

However, the TPA results of the samples frozen in air tunnel indicate that slow freezing produces pasta with less hardness, less consistency and consequently, less masticability than the unfrozen product. These differences confirm the possibility of structural damage. Only the springiness is not affected by air blast freezing.

Finally, no evidence of the effect of freezing conditions on adhesiveness was found.

3.4. Rheological analysis

3.4.1. Relaxation test

Fig. 3 shows the evolution of F/F_0 with time, obtained from the relaxation test, for both fresh cooked and frozen cooked pasta. These results were adjusted considering one simple element and three composed elements of the generalized Maxwell model. The figure includes the curve calculated with Eq. (2).

The parameters obtained from the above-mentioned model, A_∞, A_1, A_2, A_3, τ_1, τ_2, and τ_3 are detailed in Table 3. From these values and Eq. (4) the elastic and viscous modulus, E_1, E_2, E_3, η_1, η_2 and η_3, were calculated and presented in Table 4. In these results no significative differences were observed between the elastic modulus. However the viscous component of the air blast tunnel frozen sample was considerably lower than that of the other two samples.

3.4.2. Dynamic oscillatory test

The results of dynamic rheological assays are expressed in terms of storage modulus G' and loss modulus G''. Fig. 4 shows these results in function of oscillation frequency for both cooked and frozen cooked pasta.

From the results, it is evident that G' is greater than G'', in the whole range of studied frequencies, indicating the semi-solid

Table 3
Parameters of Maxwell generalized model of fresh cooked and frozen cooked pasta

	Fresh		Cryogenic		Air blast tunnel	
	Average	SD	Average	SD	Average	SD
A_∞	0.647^a	0.084	0.632^a	0.053	0.583^a	0.059
A_1	0.097^a	0.022	0.103^a	0.036	0.110^a	0.027
τ_1	2.879^a	0.362	2.990^a	0.480	2.194^a	0.471
A_2	0.101^a	0.033	0.087^a	0.029	0.118^a	0.042
τ_2	20.310^a	3.381	19.560^a	4.130	25.283^a	3.702
A_3	0.145^a	0.023	0.157^a	0.038	0.187^a	0.031
τ_3	195.19^a	12.413	177.41^a	18.567	187.75^a	12.017
R^2	0.997		0.997		0.998	

Mean values in the same row followed by same letter do not differ ($\alpha = 0.05$).

Table 4
Viscoelastic properties of fresh cooked and frozen cooked pasta

	Fresh		Cryogenic		Air blast tunnel	
	Average	SD	Average	SD	Average	SD
F_0 (N)	12.7[a]	0.920	10.61[a]	1.060	9.87[a]	1.233
E_1 (kPa)	0.157[a]	0.022	0.139[a]	0.018	0.138[a]	0.019
E_2 (kPa)	0.163[a]	0.050	0.118[a]	0.051	0.148[a]	0.063
E_3 (kPa)	0.235[a]	0.045	0.212[a]	0.033	0.235[a]	0.059
η_1 (10^{-4} Pa s)	0.452[a]	0.042	0.416[a]	0.038	0.303[b]	0.039
η_2 (10^{-4} Pa s)	3.318[a]	0.323	3.701[a]	0.458	2.300[b]	0.344
η_3 (10^{-4} Pa s)	45.788[a]	7.452	37.646[a]	8.906	44.143[a]	6.297

Mean values in the same row followed by same letter do not differ ($\alpha = 0.05$).

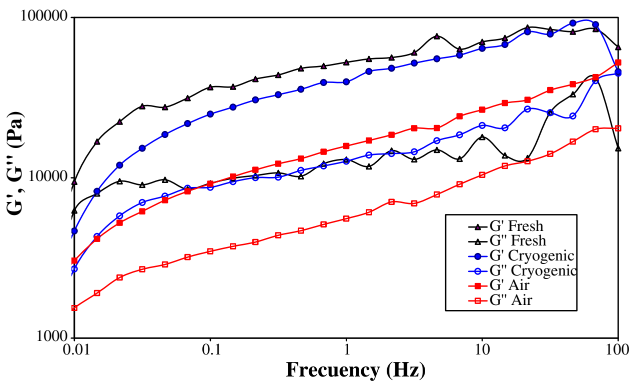

Fig. 4. G' and G'' vs. frequency of fresh cooked and frozen cooked pasta.

behavior of the cooked and frozen cooked pasta (Giborau et al., 1994).

Takhar et al. (2006) studied the viscoelastic properties and glass transition behavior of pasta at five different water content levels, and also concluded that pasta with high moisture content behaves as a viscoplastic material.

Table 5 shows the values of G', G'', and $\tan\delta$ for 1 Hz. The modulus G' and G'' for both frozen samples were significatively lower than those of the fresh cooked sample. This behavior could be due to a weakening of the net produced by the freezing/thawing process, which was more evident in slow freezing conditions.

An indicator of the solid-like, liquid-like balance of a viscoelastic material is the phase angle δ, 0° representing an ideal elastic solid, and 90° representing an ideal viscous liquid. Accordingly, for $\tan\delta < 1$ ($G'' < G'$) a more solid-like behavior is observed, while for $\tan\delta > 1$ ($G'' > G'$) a more liquid-like behavior is observed. The value of $\tan\delta$ for fresh cooked sample are in the range of the values reported by Ross (2006) for cooked Asian noodles indicating primarily solid-like behavior ($0.15 < \tan\delta < 0.25$). The increase in $\tan\delta$ values for both freezing conditions indicates that freezing provokes a loss of solid-like behavior and, consequently, an increase of liquid-like behavior. In the same sense, Ribotta et al. (2004) observed a reduction in dough firmness and elasticity caused by freezing and frozen storage.

Table 5
Parameters of dynamic oscillatory tests of fresh cooked and frozen cooked pasta

	Fresh		Cryogenic		Air blast tunnel	
	Average	SD	Average	SD	Average	SD
G' (kPa)	52.51[a]	2.15	39.68[b]	3.37	20.37[c]	3.09
G'' (kPa)	13.00[a]	0.82	12.68[a]	1.16	6.92[b]	1.44
$\tan\delta$	0.2476[a]	0.0181	0.3195[b]	0.0212	0.3250[b]	0.0175

Mean values in the same row followed by same letter do not differ ($\alpha = 0.05$).

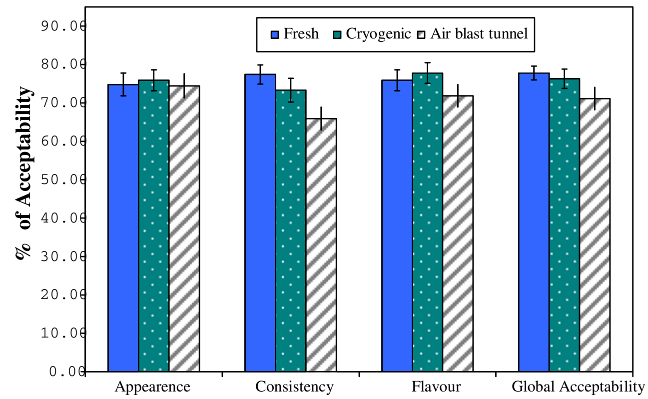

Fig. 5. Sensory analysis on acceptability of fresh cooked and frozen cooked pasta.

An aspect to be remarked is that the results obtained by dynamic oscillatory tests (which applied small deformations) can be correlated with the results of the TPA analysis (which applied large deformations), with good agreement. For example a linear relationship was found between storage modulus G' (from Table 5) and hardness (from Table 2), with $r^2 = 0.97$.

3.5. Sensory analysis

Results from the acceptability study are shown in Fig. 5. The values in this figure indicate the percentage of acceptability in each attribute: appearance, flavor, consistency and general acceptability, obtained from the marks done in the hedonic scale used in the evaluation sheets.

These results indicate that pasta frozen in air tunnel had lower values of flavor and consistency, which negatively impact in the general acceptability.

Analysis of variance confirms that the effect of sample (fresh, cryogenic and air blast tunnel) was not significant only on the appearance. Differences among samples were significant on flavor, consistency and global acceptability ($P < 0.05$).

Differences in consistency and flavor could be attributed to differences in the texture and moisture content of pasta.

4. Conclusions

Freezing experiments confirm that cryogenic freezing is an effective way of obtaining fast freezing rates. On the contrary, freezing rates on air freezing depend on air velocity. Thus, low velocity values such as those obtained in our tunnel, will produce low freezing rates.

The textural and rheological assays confirm that fast frozen pasta quality is closer to the fresh cooked product than the slow frozen one.

Not only the TPA, but also both rheological studies, confirm that freezing produces structural damage in cooked organic pasta, the elasticity, the firmness and the water holding capacity being the more affected parameters.

The texture profile analysis demonstrated that freezing rate is directly correlated to changes in their derived parameters. In this sense, faster freezing conditions produce better quality products.

Neither the TPA, nor the relaxation test, did evidence a significant effect of the freezing rate on the pasta elasticity. However, the dynamic oscillatory test confirms an important effect of freezing process in pasta elasticity.

In this way, the combined use of rheological studies that employ small and large deformations provides us of a complete viscoelastic characterization of the sample.

A panel of untrained consumers concluded that slow freezing affects consistency, flavor and global acceptability of cooked tagliatelle.

Our results confirmed that the instrumental measurements, obtained with thawed pasta, were large enough to be detected by a consumer after reheating.

Finally, further studies are needed to determine if the differences between both freezing conditions remain after long frozen storage.

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